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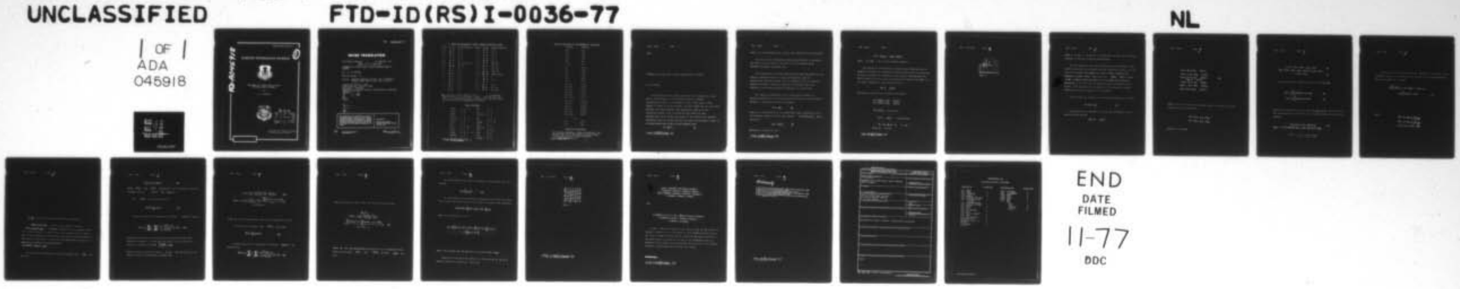

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MOVEMENT OF A WING WITH A SOLID
PROFILE NEAR A SCREEN

by

V. N. Kravets

EDITED TRANSLATION

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MOVEMENT OF A WING WITH A SOLID PROFILE NEAR A SCREEN

By: V. N. Kravets

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В в	*В в*	V, v	Т т	*Т т*	T, t
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Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
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Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and af[illegible] ь; e elsewhere. When written as ё in Russian, trans[illegible]rate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	α		Nu	Ν	ν	
Beta	Β	β			Xi	Ξ	ξ	
Gamma	Γ	γ			Omicron	Ο	ο	
Delta	Δ	δ			Pi	Π	π	
Epsilon	Ε	ε	ϵ		Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ			Sigma	Σ	σ	ς
Eta	Η	η			Tau	Τ	τ	
Theta	Θ	θ	ϑ		Upsilon	Τ	υ	
Iota	Ι	ι			Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ	κ	Chi	Χ	χ	
Lambda	Λ	λ			Psi	Ψ	ψ	
Mu	Μ	μ			Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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0036

MOVEMENT OF A WING WITH A SOLID PROFILE NEAR A SCREEN

V. N. Kravets

We will consider the plane problem of the movement of a wing with a solid profile in the potential flow of a perfect incompressible fluid at a distance h from a solid wall or free surface (a solid or liquid screen). We will assume that the wing only perturbs the flow slightly. This assumption leads us to the linearized theory [1-3]. In order for the theory of small perturbations to be valid, the values of the velocity and pressure components must not differ greatly from their corresponding values in an unperturbed flow. This is only possible when

$$\bar{\delta} = \frac{\delta}{2b} \ll 1, \qquad (1)$$

where δ is the thickness and b is the half chord of the wing profile.

We will use the acceleration potential method [4] to determine the effect of the screen on the lift of a wing profile whose thickness satisfies condition (1).

The acceleration potential method has the same generality as the velocity potential method at small perturbations. But the acceleration potential method has the advantage over the velocity potential method of making it possible to construct the basic solution to the problem without classifying the flow first.

The linear approximation of the relationship between the velocity potential ϕ and the acceleration potential θ for stationary movement is determined by the relationship

$$\theta = -V_0\varphi_x, \qquad (2)$$

where V_0 is the velocity of the unperturbed flow. According to (1), the boundary condition on the wing surface $\varphi_n = V_0 \cos(n_*, x)$ can be written as

$$\varphi_y = -V_0 f'(x). \qquad (3)$$

Therefore, according to (2)

$$\Theta_y \doteq -V_0(\varphi_x)_y = -V_0(\varphi_y)_x = V_0^2 f''(x),$$

where $y = f(x)$ is the wing profile equation.

The problem of determining the acceleration potential can be reduced to solving the following boundary problem: find the function of θ(x, y) which is the solution to the Laplace equation over the entire plane of flow Ω, with the exception of segment S_p from -b to +b, which replaces the wing profile (Fig. 1):

$$\Delta\Theta = 0 \quad (g \in \Omega),$$

and which satisfies these boundary conditions:

$$\Theta_{+y} = V_0^2 f_2''(x) = F_2(x) \quad (x \in S_{p+}),$$
$$\Theta_{-y} = V_0^2 f_1''(x) = F_1(x) \quad (x \in S_{p-}).$$

$\Theta_y = 0 (x \in L)$ - solid wall.

$\Theta_x = 0 \quad (x \in L)$ - free surface

$$\Theta_- - \Theta_+ = |\Theta| = 0 \quad \text{at} \quad x = \mp b,$$
$$\Theta \to 0 \quad \text{at} \quad x \to \mp\infty.$$

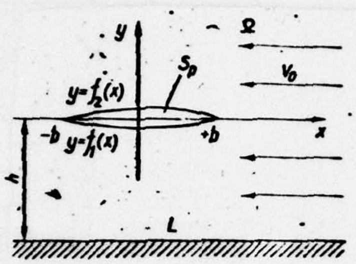

Fig. 1.

where $y = f_1(x)$, $y = f_2(x)$ are the equations for the lower and upper surfaces of the wing profile, respectively.

We will construct the simple formula for the solution to this boundary problem by introducing integral operators A_1 and A_2 of the type of potential of a binary and simple layer, respectively, assigned in space $C^k(s)$ with values in $C^m(\Omega)$ (metric space $C^m(\Omega)$ contains functions which are continuous up to the m-th derivative in the Ω-region of Euclidian space R^2 occupied by the fluid). After assigning the structure of the operators, we will construct the actual solution to the problem.

We will find the solution to the boundary problem in the form

$$\Theta = A_1\gamma_1 + A_2\gamma_2. \tag{4}$$

The properties of operators A_1 and A_2 are determined by the above boundary problem

$$\Delta A_1\gamma_1 = 0 \qquad (p \in \Omega).$$

$$
\begin{aligned}
&A_{1+}\gamma_1 = \frac{1}{2}\gamma_1 + \bar{A}_1\gamma_1 && (g \in S_{p+}),\\
&A_{1-}\gamma_1 = -\frac{1}{2}\gamma_1 + \bar{A}_1\gamma_1 && (g \in S_{p-}),\\
&A_{1\nu+}\gamma_1 = A_{1\nu-}\gamma_1 = \bar{A}_{1\nu}\gamma_1 && (g \in S_p);\\
&\Delta A_2\gamma_2 = 0 && (p \in \Omega),\\
&A_{2+}\gamma_2 = A_{2-}\gamma_2 = \bar{A}_2\gamma_2 && (g \in S_p),\\
&A_{2\nu+}\gamma_2 = -\frac{1}{2}\gamma_2 + \bar{A}_{2\nu}\gamma_2 && (g \in S_{p+}),\\
&A_{2\nu-}\gamma_2 = \frac{1}{2}\gamma_2 + \bar{A}_{2\nu}\gamma_2 && (g \in S_{p-}),
\end{aligned} \tag{5}
$$

where p and g are points of Euclidian space R^2. Based on (4) and properties (5), we will have

$$
\begin{aligned}
\Theta_{+\nu} &= \bar{A}_{1\nu}\gamma_1 - \frac{1}{2}\gamma_2 + \bar{A}_{2\nu}\gamma_2,\\
\Theta_{-\nu} &= \bar{A}_{1\nu}\gamma_1 + \frac{1}{2}\gamma_2 + \bar{A}_{2\nu}\gamma_2,
\end{aligned}
$$

whence we will find

$$\gamma_2 = \Theta_{-v} - \Theta_{+v} = F_1(x) - F_2(x) = [F(x)], \tag{6}$$

$$\overline{A}_{1y}\gamma_1 = \frac{1}{2}(\Theta_{-v} + \Theta_{+v}) - \overline{A}_{2y}\gamma_2 = \frac{1}{2}[F_1(x) + F_2(x)] - \overline{A}_{2y}\gamma_2 = = F_{cp}(x) - \overline{A}_{2y}\gamma_2. \tag{7}$$

we will represent operators A_1 and A_2 in the form

$$A_1\gamma_1 = \frac{V_0}{2\pi}\int_{-b}^{+b}\gamma_1(\xi)\frac{\partial}{\partial\eta}G(x, y, \xi, \eta)\,d\xi, \tag{8}$$

$$A_2\gamma_2 = \frac{1}{2\pi}\int_{-b}^{+b}\gamma_2(\xi)\,G(x, y, \xi, \eta)\,d\xi. \tag{9}$$

Here we will represent Green's function $G(x, y, \xi, \eta)$, which satisfies the conditions on a solid wall (free surface) and on to infinity as follows:

$$G(x, y, \xi, n) = \ln\frac{1}{r} + \operatorname{sign} F \ln\frac{1}{r_1}, \tag{10}$$

where $r = \sqrt{(x-\xi)^2 + (y-\eta)^2}$, $r_1 = \sqrt{(x-\xi)^2 + (y+\eta+2h)^2}$,

$$\operatorname{sign} F = \begin{cases} +1 & \text{- solid wall,} \\ -1 & \text{- free surface.} \end{cases}$$

According to (6)-(10) and condition $\Theta \to 0$ at $x \to +\infty$ the integral equation for determining the density of the distribution of the vortex layer is as follows

$$\frac{1}{2\pi}\int_{-1}^{+1}\bar{\gamma}_1(\bar{s})\left[\frac{1}{\bar{x}-\bar{s}} - G(\bar{x}-\bar{s})\right]d\bar{s} = -[f'(\bar{x})+\alpha] +$$

$$+\frac{1}{2\pi}\int_{-1}^{+1}[F(\bar{s})]_1 G_1(\bar{x}-\bar{s})\,d\bar{s}, \tag{11}$$

where

$$G(\bar{x}-\bar{s}) = \operatorname{sign} F\frac{\bar{x}-\bar{s}}{(\bar{x}-\bar{s})^2+16\bar{h}^2},$$

$$G_1(\bar{x}-\bar{s}) = \operatorname{sign} F\frac{4\bar{h}}{(\bar{x}-\bar{s})^2+16\bar{h}^2},$$

$$\bar{x} = \frac{x}{b},\ \bar{s} = \frac{s}{b},\ \bar{\gamma}_1(\bar{s}) = \frac{\gamma_1(s)}{V_0},$$

$\bar{h} = \frac{h}{2b}$ is the relative distance from the screen,

$[F(\bar{x})]_1 = f_2'(\bar{x}) - f_1'(\bar{x})$, α is a small angle of attack,

$f^*(\bar{x}) = \frac{1}{2}[f_2'(\bar{x}) + f_1'(\bar{x})]$. Integral equation (11) is singular with a root which contains a regular part. The presence of the regular part greatly complicates the process of finding a closed solution to the equation. Therefore, we will find the approximate solution to equation (11) using the small parameter
$\tau = \sqrt{4\bar{h}^2 + 1} - 2\bar{h}\ (0 < \tau < 1)$ [4].

We will find the solution to integral equation (11) $\bar{\gamma}_1(\bar{x})$ in the form

$$\bar{\gamma}_1(\bar{x}) = \bar{\gamma}_1^{(1)}(\bar{x}) + \bar{\gamma}_1^{(2)}(\bar{x}), \qquad (12)$$

where $\bar{\gamma}_1^{(1)}(\bar{x})$ and $\bar{\gamma}^{(2)}(\bar{x})$ correspond to the solution of integral equation (11) at $f'(\bar{x}) = 0$ and $|F(\bar{x})|_1 = 0.$

For $\gamma_1^{(1)}(\bar{x})$ the solution will be

$$\bar{\gamma}_1^{(1)}(\bar{x}) = \sum_{n=0}^{\infty} \gamma_{1n}(\bar{x})\,\tau^{2n}. \qquad (13)$$

We will represent the expansion of function $G(\bar{x}-\bar{s})$ as [4]:

$$G(\bar{x}-\bar{s}) = \sum_{n=2,4,\ldots}^{\infty} \tau^n \sum_{p=2,4,\ldots}^{n} \frac{(-1)^{\frac{p}{2}-1}\left(\frac{n+p}{2}-1\right)!}{(p-1)!\left(\frac{n-p}{2}\right)!}(\bar{x}-\bar{s})^{p-1}. \qquad (14)$$

Substituting (13) and (14) in (11) and equating the terms with identical exponents τ on the left and right, we will obtain the series of integral equations $\int_{-1}^{+1} \frac{\varphi(\bar{s})\,d\bar{s}}{\bar{x}-\bar{s}} = \Psi(\bar{x}),$

whose solutions, limited at point $\bar{x} = -1,$ are determined by the Cauchy interval transformation formula [5]:

$$\gamma_{10}(\bar{x}) = \frac{2}{\pi}\sqrt{\frac{1+\bar{x}}{1-\bar{x}}}\int_{-1}^{+1}\sqrt{\frac{1-\bar{s}}{1+\bar{s}}}\cdot\frac{f'(\bar{s})+\alpha}{\bar{x}-\bar{s}}\,d\bar{s}, \qquad (15)$$

$$\bar{\gamma}_{1n}(\bar{x}) = -\frac{1}{\pi^2}\sqrt{\frac{1+\bar{x}}{1-\bar{x}}}\int_{-1}^{+1}\sqrt{\frac{1-\bar{s}}{1+\bar{s}}}\cdot\frac{\int_{-1}^{+1}\sum_{m=0}^{n-1}\bar{\gamma}_{1m}(\bar{p})\,K_{1\,(n-m-1)}(\bar{s}-\bar{p})\,d\bar{p}}{\bar{x}-\bar{s}}\,d\bar{s}$$

$$(n = 1, 2, 3, \ldots),$$

where K_{1i} are the expressions found by the expansion of (14).

We will find the solution for $\bar{\gamma}_1^{(2)}(\bar{x})$ as follows

$$\bar{\gamma}_1^{(2}(\bar{x}) = \sum_{n=0}^{\infty}\bar{\gamma}_{2n}(\bar{x})\,\tau^{2n+1}. \qquad (16)$$

We will represent the expansion of function $G_1(\bar{x}-\bar{s})$ as follows [4]:

$$G_1(\bar{x}-\bar{s}) = \sum_{n=1,3,\ldots}^{\infty}\tau^n\sum_{p=1,3,\ldots}^{n}\frac{(-1)^{\frac{p-1}{2}}\left(\frac{n+p}{2}-1\right)!}{(p-1)!\left(\frac{n-p}{2}\right)!}(\bar{x}-\bar{s})^{p-1}. \qquad (17)$$

Then, according to (11), (14), (16) and (17) we will have

$$\bar{\gamma}_{20} = 0,$$
$$\bar{\gamma}_{2n}(\bar{x}) = -\frac{1}{\pi^2}\sqrt{\frac{1+\bar{x}}{1-\bar{x}}}\int_{-1}^{+1}\sqrt{\frac{1-\bar{s}}{1+\bar{s}}}\times$$
$$\times\frac{\int_{-1}^{+1}\left\{[F(\bar{p})]_1 Q_{1n}(\bar{s}-\bar{p})+\sum_{m=0}^{n-1}\bar{\gamma}_{2m}(\bar{p})K_{1\,(n-m-1)}(\bar{s}-\bar{p})\right\}d\bar{p}}{\bar{x}-\bar{s}}\,d\bar{s} \quad (18)$$
$$(n = 1, 2, 3, \ldots),$$

where Q_{ij} are the expressions determined by the expansion of (17). Having expressions $\bar{\gamma}_1^{(1)}(\bar{x})$ and $\bar{\gamma}_1^{(2)}(\bar{x})$, we find $\bar{\gamma}_1(\bar{x})$ by (12).

We will determine the lift coefficient of the profile with the formula

$$C_y = \int_{-1}^{+1} \bar{\gamma}_1(\bar{x})\, d\bar{x}. \qquad (19)$$

We will consider the practically significant case when the shape of the upper and lower sides of the profile is given by the equations

$$y_B(\bar{x}) = f_2(\bar{x}) = \sum_{n=1}^{m} b_{1n}\bar{x}^n, \quad y_H(\bar{x}) = f_1(\bar{x}) = \sum_{n=1}^{m} b_{2n}\bar{x}^n.$$

Then, with accuracy up to τ^8

$$C_y = 2\pi \left[\alpha\left(1 + \tau^2 + \frac{1}{2}\tau^4 + \frac{3}{4}\tau^6 + \frac{39}{32}\tau^8\right) + A_{11} + \sum_{n=1}^{4} A_{1(2n)}\tau^{2n} + \right. \\ \left. + \frac{1}{2}\sum_{n=1}^{3} A_{1(2n+1)}\tau^{2n+1} \right],$$

where coefficients A_{1i} are expressed by coefficients b_{1i}, b_{2i}.

Example. We will find the effect of a solid screen on C_y of a profile similar to profile BS - 80/o [6]:

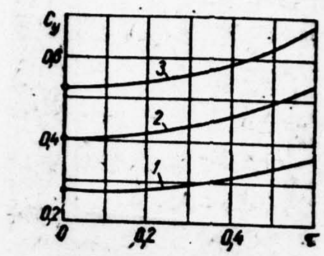

Fig. 2.

$$y_{\text{в}}(\bar{x}) = -0{,}062608\bar{x}^6 - 0{,}071136\bar{x}^5 + 0{,}057216\bar{x}^4 + 0{,}025948\bar{x}^3 - 0{,}087347\bar{x}^2 + 0{,}052883\bar{x} + 0{,}092738,$$

$$y_{\text{н}}(\bar{x}) = 0{,}035200\bar{x}^6 + 0{,}034624\bar{x}^5 - 0{,}022400\bar{x}^4 - 0{,}025948\bar{x}^3 + 0{,}039800\bar{x}^2 - 0{,}008676\bar{x} - 0{,}052600.$$

Then

$$C_y = 2\pi\left[\alpha\left(1 + \tau^2 + \frac{1}{2}\tau^4 + \frac{3}{4}\tau^6 + \frac{39}{32}\tau^8\right) + 0{,}011231 + 0{,}010963\tau^2 - 0{,}025648\tau^3 + 0{,}014759\tau^4 - 0{,}05555\tau^5 + 0{,}009490\tau^6 - 0{,}020784\tau^7 + 0{,}013900\tau^8\right].$$

Figure 2 shows the curves of the change in C_y of the profile at angles of attack of α = 2.2° (curve 1); 3.5° (curve 2); 4.8° (curve 3). Here the small circles show the values of C_y of the profile at the same angles of attack in the case of an unlimited fluid. By analyzing these curves, we can conclude that the lift of the profile increases considerably when it nears the screen.

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